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PRODUCTION OF ULTRA-HIGH FREQUENCY RADIO WAVES BY ELECTRONIC OSCILLATIONS*

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ABSTRACT Detailed investigation has been made of the mode of production of ultra-high frequency radio waves by electronic oscillations in a triode valve. The effect of emission current and grid potential on the lengths and intensity of the generated waves has been critically examined and a new relation between them has been derived, *viz.*, $\lambda E_g^{\frac{1}{2}} I_s^{\frac{1}{4}} =$ constant, where λ is the wavelength generated, E_g is the grid potential, and I_s is the emission current. This relation has been experimentally verified by means of Barkhausen and Kurz oscillator with modification of Gill and Morrell. It is concluded that the emission current plays an important part in predicting the lengths of the generated waves. It has been observed that, for the same grid potential, the intensity of the generated waves increased with the increase of emission current. The lengths of such waves, however, decreased when the emission current was increased. The waves generated in the present investigations were of Gill and Morrell type as has been shown by the method of Cockburn from the variation of anode current with grid potential. It has also been shown that for such oscillations the lengths of the generated waves were altered with the variation of length of external circuit associated with the valve.

INTRODUCTION

With the advent of television and aircraft communications attention has been greatly centred in the study of generation of continuous radio waves of ultra-high frequencies. It has now become customary to call the radio waves below 10 metres as ' ultra short waves ' and those below 1 metre as ' micro waves.'

The only satisfactory method till now known for powerful production of these ultra-high frequency waves is based on the use of electronic oscillations in a triode and in magnetron valves. In 1919, Whiddington [1] generated radio waves of about 500 metres by the electronic oscillations in a soft triode with high positive grid. Near about the same time Barkhausen and Kurz[2] succeeded in producing radio waves of about 1 metre length by using hard triode valves with

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high positive grid compared to the anode and put forward the theory of the same. According to their theory the wavelength produced should depend only on the dimensions of the electrodes and the working conditions of the tube.

Since the time of Barkhausen and Kurz various investigators [3-11] have tried to verify the laws established by them, and in many instances results have been obtained which do not completely agree with the original theory of Barkhausen and Kurz. Gill and Morrell,[3] for instance, reported in 1922 that the external circuit connected with the valve plays an important part in prediction of the wavelength produced. The results of Gill and Morrell were confirmed by other workers in this field. It is, however, now admitted that there are two types of oscillations produced inside a vacuum tube. One is the Barkhausen and Kurz oscillation which is independent of the external circuit and the other is the Gill and Morrell type which is dependent on the external circuit. Cockburn [11] has, however, shown that there is no fundamental difference between these two types of oscillations and he has pointed out that the Gill and Morrell oscillations occur when the external circuit associated with the valve happens to be in resonance with Barkhausen and Kurz oscillations.

In the present investigations the study has been made of the mode of production of ultra-high frequency waves by electronic oscillations in a triode valve with high positive potential being applied to the grid. A preliminary note [12] on this work has already been published recently. The relations existing between the grid potential applied, emission current and the wavelengths produced have been critically examined and it has been observed that the consideration of emission current is not less important than the grid potential in establishing such relation. Thus a new equation indicating the connection between the wavelengths produced and both the grid potential and emission current has been derived from the equations of Barkhausen and Kurz [2] and Tank.[5] This equation has been found to agree very closely with the observed results for a considerable range of grid potentials. It was also observed that the intensity of the generated waves was increased as the emission current was increased for the same grid potential. The wavelengths, however, decreased with the increase of the emission current, as has also been observed by other investigators mentioned in the following section. In the present investigation all the observations were taken in the region of Gill and Morrell as the wavelengths were found to vary with the external circuit. This has also been substantiated by the curves showing the variation of anode current with increasing grid potential.

THEORY

For plane electrodes, Barkhausen and Kurz worked out a formula showing the relation between the wavelength produced, distances between the filament and anode, and filament and grid and the potentials applied to the anode and grid compared to the filament. Subsequently Scheibe [4] gave more rigorous formula for cylindrical electrodes. Tank,[5] Gill [13] and various other workers pointed out later on that the relations given by Barkhausen and Kurz and Scheibe were not adequate to establish the wavelength generated, as they found that the wave-length decreased when the emission current was increased. Gill worked out a theoretical formula which included the emission current also. Potapenko,[14] however, investigated experimentally the formula of Gill in details. The results of Potapenko showed considerable discrepancies between calculated and observed values. Very recently Gill [15] has produced ultra-short waves of length 1 to 3 metres by split anode valve and has suggested the explanation of the reduction of wavelength with increase in emission for a fixed grid voltage. Tonks[7] gave a physical explanation of the possibility of decrease of the wavelength produced as the emission current is increased, a brief description of which will be given below for reference.

When the emission currents are small, the electrons which leave the filament are accelerated by the positive grid till they pass through it and are acted by retarding field when they enter the grid-anode space. Since the anode is originally at the same potential as the filament, the retarding electrons will have zero velocity when they reach the anode and may be collected on it or reflected. In this case the space charge in the grid-anode space depends on the total electron current and accordingly the potential distribution between the grid and anode is the same as in the case when the plate itself becomes the emitter of electrons. But as the emission from the filament is increased the space-charge in the grid-anode space also increases and makes the field zero even at a space nearer to the grid than the plate itself. Consequently the electrons turn back from the plane without reaching the plate. This plane of zero potential, which is called 'virtual cathode,' will move away from the anode towards the grid as the emission current is increased. This will decrease the transit time of the electrons in grid-anode space and consequently the wavelength will be decreased.

The various relations with the wavelengths produced, grid potential applied and the emission current as mentioned previously, have beeen critically studied by us and it has been observed that the consideration of the emission current is as important as the grid potential in predicting the lengths of the waves produced by electronic oscillations. A new relation connecting the wavelength produced and both the grid potential and emission current has been derived by the combination of the equations of Barkhausen and Kurz and Tank.

The relation of Barkhausen and Kurz for the wavelength genarated in a triode valve with cylindrical grid and anode is given by

$$\lambda = \frac{10^3}{E_g^{\frac{1}{2}}} \left[\frac{d_a E_g - d_g E_a}{E_g - E_a} \right]$$

where E_g and E_a are grid and anode potentials in volts, d_g and d_a are the diameters of the grid and anode in cms. respectively and λ is the wavelength generated in cms.

For a simplified case as employed in the present investigations, when the anode is maintained at the same potential as the negative end of the filament, we get

$$\lambda^2 E_g = \text{constant} \qquad \ldots \quad (1)$$

The relation of Tank for the wavelength generated and the emission current is given by

$$\lambda^3 I_e = \text{constant} \qquad \ldots \quad (2)$$

From equations (1) and (2) we get

$$\lambda E_g^{\frac{1}{2}} I_e^{\frac{1}{3}} = \text{constant.} \qquad \ldots \quad (3)$$

The above equation has been experimentally verified as described in later section.

EXPERIMENTAL ARRANGEMENT AND OBSERVATIONS

The apparatus used for the present investigations was almost similar to that used by Barkhausen and Kurz after the modification of Gill and Morrell. A pair of Lecher wires LL (Fig. 1), each 130 cm. long and spaced 5·5 cm. apart, was connected to the grid and anode of a triode valve. The anode and grid were concentric cylinders encircling the straight filament at the common central axis. The desired effective length of the external circuit was obtained by altering the position of a sliding bridge consisting of a fixed condenser C of 0·002 micro-farad capacity. A high variable positive potential was applied to the grid through a filter F, which was connected to 440-volts D. C. mains. The anode was connected to the negative end of the filament through a sensitive calibrated galvanometer CG. The grid and anode potential leads were connected to the two ends of the bridge condenser C as shown in the figure. The filament current was measured with an ammeter A in Fig. 1. A milli-ammeter MA in the grid circuit and the galvanometer CG in the anode circuit together measured the total emission current. After the filament was heated to the desired temperature, the potential applied to the grid was measured by means of an electrostatic voltmeter to avoid any leakage of current through the instrument

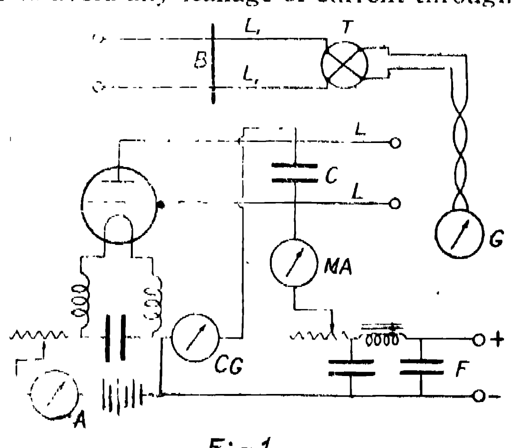

Fig 1.

The lengths of the ultra-high frequency waves generated were measured by an auxiliary Lecher wire system L_1L_1, loosely coupled to the oscillator. Two ends of the auxiliary Lecher wires were joined to the heater terminals of the vacuo thermo junction T which was connected to a sensitive galvanometer G. A metal sliding-bridge B was moved on the auxiliary Lecher wire system in order to get the position of maximum current in the glavanometer from which the wavelength could be determined. Equation (3) of the last section was verified with various lengths of the external circuit. The wavelengths produced have been noted with different grid potentials and different emission currents obtained by changing the filament heating current. Total emission current was obtained from the sum of grid and anode currents Two typical sets of observations verifying equation (3) are given below in Tables I and II for two fixed lengths of the external circuit. The second column of these tables show the values of total emission current. For observations in Table I the bridging condenser was placed at 50 cms. away from the grid terminal and for those in Table II it was placed 100 cms. away

TABLE I

Grid potential (E_g) in volts.	Emission current (I_e) in milli-amperes.	Wavelength generated (λ) in cms.	$\lambda E_g^{\frac{1}{2}} I_e^{\frac{1}{4}}$.
80	50	171	573·3
80	68	156	569·5
80	76	152	590·2
100	52	152	582·2
100	70	144	593·4
100	98	128	589·6
120	52	144	588·0
120	115	100	586·1
120	160	94	576·5
140	65	120	570·9
140	110	106	587·2
160	80	106	577·9

TABLE II

Grid potential (E_g) in volts.	Emission current (I_e) in milli-amperes.	Wavelength generated (λ) in cms.	$\lambda E_g^{\frac{1}{2}} I_e^{\frac{1}{3}}$.
80	60	194	679 4
80	68	186	679·0
80	70	184	677·0
100	68	168	687·7
100	95	150	684·4
100	95	144	675·4
120	72	148	671·6
120	120	126	681·0
120	145	118	679·2
140	80	132	673·2
140	140	110	675·0

It will be noted from the above tables that the values in the last column are nearly constant. The numerical value of this constant, however, changes by a small amount with the variation of the external circuit associated with the valve. This is due to the change in wavelength produced by altering the length of the external circuit as the observations were taken in the region of Gill and Morreil. It will be further observed from each of the above tables that, for the same value of the grid potential, the length of the emitted wave was reduced as the emission current was increased. The intensity of the oscillations, however, increased with the increase of the emission current.

Table III shows below how the wavelength varies with the gradual change of length of the associated external circuit.

Grid Potential = 80 Volts.
Emission Current = 55 Milli-amperes.

TABLE III

Length of the external circuit in cms.	Wavelength generated (λ) in cms.
0	144·0
25	148·6
50	150·4
75	156·0
100	158·8
125	162·6

That the waves generated for the experimental observations were of the Gill and Morrell type was further tested by the method of Cockburn by drawing the curves showing the variation of anode current with grid potential. The portions of such curves within which the anode current remains constant, indicate the

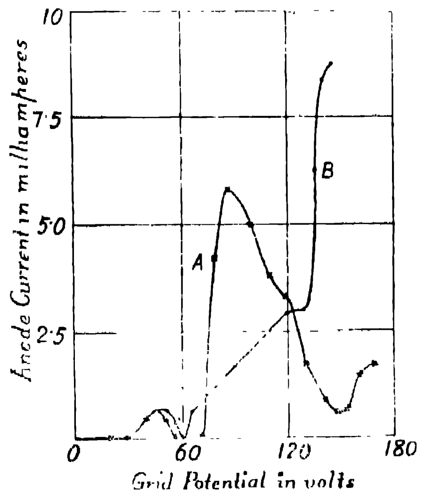

Fig. 2

region of grid potentials for the production of Barkhausen and Kurz oscillations. The other parts of the curve in which the anode current is constantly varying, correspond to Gill and Morrell oscillations. The variations of anode current with grid potential have been shown in Fig. 2. Curves A and B have been drawn for two values of filament-heating currents used in the above experiments. It will be observed from these curves that, within the limits of grid potentials (80 to 140 volts) used in the above experiments, there is no part of the curves for which the anode current remained constant for a considerable range of grid potential.

SUMMARY AND CONCLUSION

A detailed study of the generation of ultra-high frequency radio waves by electronic oscillations in a triode valve has been made in the present investigation. The effect of the emission current on the lengths and intensity of the waves generated has been critically examined and a relation concerning the emission current, grid potential and the wavelength generated has been derived. This has been experimentally verified and typical observations have been recorded. It has been concluded that the consideration of emission current is of considerable importance in predicting the wavelengths generated by these oscillations. It has been found that the lengths of the generated waves decreased as the emission current was increased at the same value of grid voltage. The intensity of the waves, however, increased under the same condition. The oscillations generated in the present investigations belonged to Gill and Morrell type. This has been shown by the method of Cockburn by drawing curves indicating the variation of of anode current with grid potentials. It has been further shown that, for such oscillations, the lengths of waves generated altered with the change of length of the external circuit associated with the valve.

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